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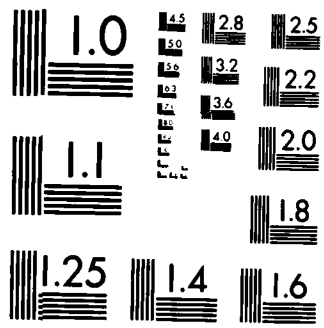

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The research group of which the author is a member has been studying various techniques of automated digital image feature extraction for several years. One increasingly thorny problem has been how to make decisions when the available information is incomplete or uncertain. Classical Bayesian probality theory has been used in the past, with limited success at best. Within the last year or so, we have been exploring alternatives to Bayesian probability, with emphasis on two in particular; Shafer's theory of evidence, and Zadeh's fuzzy logic. We feel that all three theories have something to offer to help solve the feature extraction

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BAYESIAN,EVIDENCE,FUZZY:
WHICH THEORY WORKS BEST WHEN REASONING WITH UNCERTAIN KNOWLEDGE?

James A. Shine
U.S. Army Engineer Topographic Laboratory
Ft. Belvoir,VA 22060-5546

ABSTRACT

The research group of which the author is a member has been studying various techniques of automated digital image feature extraction for several years. One increasingly thorny problem has been how to make decisions when the available information is incomplete or uncertain. Classical Bayesian probability theory has been used in the past,with limited success at best. Within the last year or so, we have been exploring alternatives to Bayesian probability, with emphasis on two in particular: Shafer's theory of evidence, and Zadeh's fuzzy logic. We feel that all three theories have something to offer to help solve the feature extraction problem, and we are currently looking toward combining aspects of all three theories under one roof.

INTRODUCTION

Feature extraction - looking at an image and identifying one region as (for example) a lake, another a building, another a forest - is something that humans can do rather easily, but computers find it considerably more difficult. Since there are many situations where humans are not available for this task, research in automated feature extraction is watched (and funded) eagerly by many groups, including the surveying and mapping community. This paper describes three theories that can be applied to the feature extraction decision process and compares their strengths and weaknesses. The first theory (Bayesian) shows the emphasis of the past on precise mathematical algorithms, and the other two theories (Evidence and Fuzzy) show the emphasis of the present on less precise, knowledge-based information to supplement the old techniques and hopefully improve the decision-making process.

BAYESIAN DECISION THEORY

Bayesian decision theory is based on fundamental probability theory. A variable may take any of a set number of values; each value has a specific probability associated with it, and the probabilities of all possible values add to one. In the feature extraction problem the variable is a pixel and the values it can take are the possible classifications for that pixel (forest, lake, building, etc.). Bayesian decision theory assumes a predefined distribution of values for a variable and using this distribution decides which value a variable is most likely to be in a given case. For feature extraction, statistics (grey shade, gradients, neighboring pixels, etc.) are computed for the pixel in question and then are compared with statistics that have been computed for test areas of the different classes. The pixel is classified as the class which its statistics match best. Tests to date have met with limited success at best. Test statistics are not always accurate; the probabilities are not always as exact as the

mathematics requires; and there is no room for commonsense information, such as: buildings are usually next to roads. This last deficiency is especially important since commonsense knowledge (in our opinion) must be integrated into the decision process if automated feature extraction is ever to approach the level of human feature extraction.

EVIDENCE THEORY

Evidence theory was developed by Shafer in the mid-1970s. Evidence theory is analogous to Bayesian decision theory, with "belief functions" replacing the probabilities for each of the possible values. The key difference is that belief functions do not have to add to one, while Bayesian probabilities do. This allows a "degree of doubt" in cases where uncertainty exists, and allows the belief functions to be changed when new evidence arrives (for example, commonsense information). The evidence theory framework also allows classification when more than one image of the same area is being examined (for example, the different spectral bands of a LANDSAT image).

FUZZY LOGIC

Fuzzy logic was developed by Zadeh in the late 1960s. The theory deals with "linguistic variables" and their values. A linguistic variable is one whose values are words instead of numbers. For example, if terrain slope is a linguistic variable, then the terms flat, rough, steep, and very steep may be regarded as values of terrain slope. Base variables take numerical values which correspond in varying degrees to linguistic values (for example,10^{o}, 20^{o}, and 30^{o} slopes). Compatibility factors (also called membership functions) measure the correlation between a linguistic value and a base value, with 0 denoting no relation, 1 the strongest relation, and fractions the varying degrees in between. For example, 40^{o} slope and flat might have a compatibility function of 0.1, while 40^{o} and steep might have a compatibility function of 0.9. Fuzzy logic is very useful when trying to represent commonsense information regarding feature extraction, for example: "If an area is either a lake or a field and a road runs through it, it is probably a field." Such information is very helpful in the feature extraction process, as strictly numerical and statistical techniques (while more precise and easily represented) often fail in automated feature extraction.

CONCLUSION

All three theories discussed here - Bayesian, Evidence, and Fuzzy - have their place in automated feature extraction research. Bayesian decision theory is useful in reasonably "certain" applications where pixels are composed of certain classes of known probabilities. Evidence theory allows several images to be used and provides a framework for adding information to the decision-making process. Fuzzy logic allows imprecise "commonsense" information to be precisely represented and added to the decision-making process, which hopefully will improve the limited success achieved to date using precise mathematical algorithms.

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